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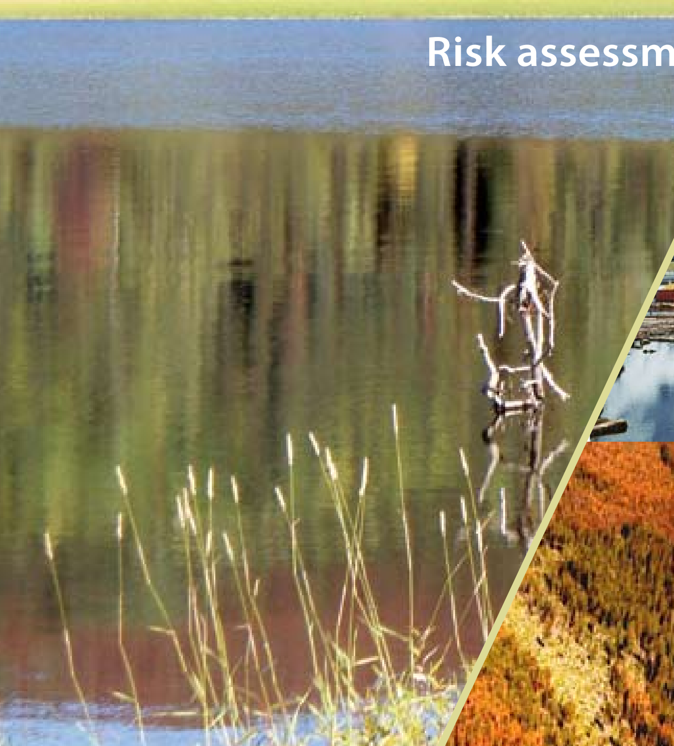
Risk assessment of the threat of mountain pine beetle to Canada's boreal and eastern pine forests



Compiled by Vince Nealis
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forest. forward.
moving beyond the pine beetle

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The Pacific Forestry Centre, Victoria, British Columbia

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Executive Summary

This report assesses the threat of the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) to Canada's boreal and eastern pine forests. It is based on available evidence and expert advice provided by researchers and forest managers at two workshops held in Edmonton, Alberta and Victoria, British Columbia during August and September of 2007. The main findings include:

- Recent spread of the mountain pine beetle outside its historical range is a consequence of both persistent short-distance diffusion and occasional long-distance dispersal of adult beetles from epidemic populations in British Columbia. These immigrants have successfully reproduced and thus are in the early stages of range extension.

- There are no evident host-related impediments to the spread of mountain pine beetle further east or north through the boreal zone as dominant boreal and eastern pine species are suitable hosts for both the mountain pine beetle and associated blue-stain fungi.

- Forest structure (e.g., age-class distribution, size and spatial distribution of host trees) in the boreal forest is less likely to favour the same high rates of spread and severe levels of damage observed in the denser, older and larger pine forests of the interior of British Columbia.

- Weather conditions of the past decade have facilitated the survival of mountain pine beetle in its expanded range but climate conditions in these regions are still relatively unfavourable, reducing the short-term risks of mountain pine beetle epidemics spreading rapidly across the boreal region. In the near future, the area of climatic suitability is expected to increase in British Columbia and northwest Alberta, especially toward the Yukon and Northwest Territories. In the more easterly portions of the boreal zone, the area of climatic suitability will decrease slightly and shift northward.

- Natural extinction of the mountain pine beetle in its expanded range is unlikely. More likely is persistence of populations outside the historical range. Even if population levels remain low, the expanded range of the beetle could create an ecological pathway across the prairie region that allows for continuing spread of the insect further east into more susceptible pine forests. Wherever suitable conditions exist within this expanded range, there is the potential for damaging outbreaks and accelerated spread.

- If mountain pine beetle outbreaks occur in the boreal zone, a reduction of timber supply from affected regions will result. Stand-level losses in terms of absolute volumes are unlikely to be as severe as those experienced in British Columbia but could still render some stands inoperable. Net economic impacts will depend heavily on the extent and timing of tree mortality and the concurrent demand for timber by the forest sector. Regulatory impacts (e.g., log transport restrictions) and changes to fibre flows may reduce operational efficiency. Trends in other resource and industry sectors will affect the capacity for communities to adapt to mountain pine beetle-related impacts on the forest sector.

- Boreal and eastern pine forests provide non-timber benefits to society. As a result of the relatively smaller scale of the forest sector in the prairie region, impacts of mountain pine beetle damage on these non-timber values may have greater significance in this region than in British Columbia. Forest management interventions may come into conflict with these non-timber values in some locations. The cost of disposing of dead-standing pine where its presence is incompatible with other values (e.g., safety concerns in public campgrounds) may also create financial impacts.

- Additional fire risks and increased uncertainty of future fire behaviour will result from damage.

- Doing nothing in response to the incursion of mountain pine beetle would exceed the risk tolerance of stakeholders in the regions under threat. A response based on current information and knowledge should include both short-term direct control and longer-term preventative management. A comprehensive response will require a variety of management actions based on objectives specific to local outbreak conditions, stand vulnerability, values at risk, and operational feasibility.

- Uncertainty over the effectiveness of management responses to the risks posed by mountain pine beetle may be reduced by addressing the information gaps identified in this report. These include refining methods used in mountain pine beetle monitoring and detection and improving information on current forest cover in areas without a forest management inventory. The most critical immediate information need is for effective mountain pine beetle monitoring and detection in areas vulnerable to the current infestation. Research priorities include enhancing knowledge of suitability of other pine species to mountain pine beetle and associated fungi, climatic suitability, and models and tools to predict mountain pine beetle dispersal, fire behaviour, economic impacts, and community adaptation strategies.

Résumé

Le présent rapport vise à évaluer la menace que pose le dendroctone du pin ponderosa (*Dendroctonus ponderosae* Hopkins) pour les pinèdes boréales et de l'Est du Canada. Il s'appuie sur les données disponibles et sur l'expertise de chercheurs et de gestionnaires forestiers qui ont participé à deux ateliers qui se sont tenus à Edmonton, Alberta, et à Victoria, Colombie-Britannique, en août et en septembre 2007. Voici les principales conclusions :

- La propagation récente du dendroctone du pin ponderosa à l'extérieur de son aire de répartition traditionnelle est une conséquence de la dispersion à petite échelle et à grande échelle occasionnelle des dendoctrones adultes issus des populations en pleine épidémie en Colombie-Britannique. Ces insectes immigrants ont réussi à se reproduire et en sont donc aux premiers stades d'une expansion de leur aire.

- Il n'y a aucune évidence qu'il y ait des facteurs reliés aux hôtes qui puissent empêcher la propagation du dendroctone du pin ponderosa vers l'est ou le nord dans la zone boréale, car les essences de pin dominantes dans les forêts boréales et de l'Est sont des hôtes convenables pour cet insecte et pour les champignons qui lui sont associés et qui causent le bleuissement du bois.

- La structure forestière (p. ex., la distribution par classes d'âges, la taille et la distribution spatiale des arbres hôtes) de la forêt boréale favorise vraisemblablement moins les mêmes taux élevés de propagation et de dommages qu'on observe dans les forêts plus denses, plus vieilles et plus étendues de l'intérieur de la Colombie-Britannique.

- Les conditions météorologiques de la dernière décennie ont facilité la survie du dendroctone du pin ponderosa dans son aire d'expansion, mais les conditions climatiques de ces régions demeurent relativement défavorables, ce qui réduit les risques à court terme d'épidémies de cet insecte qui se propageraient rapidement dans l'ensemble de la zone boréale. Dans un avenir rapproché, l'aire de compatibilité climatique devrait s'accroître en Colombie-Britannique et dans le nord-ouest de l'Alberta, particulièrement en direction du Yukon et des Territoires du Nord-Ouest. Dans les parties plus à l'est de la zone boréale, l'aire de compatibilité climatique diminuera légèrement alors qu'elle s'étendra vers le nord.

- L'extinction naturelle du dendroctone du pin ponderosa dans son aire d'expansion est improbable. Il est plus vraisemblable que les populations persisteront à l'extérieur de leur aire de répartition traditionnelle. Même si les niveaux des populations demeurent faibles, l'aire d'expansion de l'insecte pourrait ouvrir une voie écologique dans la région des Prairies, ce qui permettrait la poursuite de sa propagation vers l'est dans des pinèdes plus vulnérables. Là où les conditions adéquates existent dans l'aire d'expansion, le potentiel de pullulation dommageable et de propagation accélérée existe.

- Si des pullulations du dendroctone du pin ponderosa surviennent dans la zone boréale, il s'ensuivra une réduction de l'approvisionnement en bois dans les régions affectées. Vraisemblablement, les pertes dans les peuplements en termes de volumes absolus ne seront pas aussi élevées que celles que connaît la Colombie-Britannique, mais elles pourraient aller jusqu'à rendre certains peuplements inexploitables. Les incidences économiques nettes dépendront largement de l'étendue et du moment de la mortalité des arbres ainsi que de la demande simultanée de bois qui proviendra du secteur forestier. Les incidences de la réglementation (p. ex., les restrictions imposées au transport des billes) et les changements dans les flux de la fibre peuvent réduire l'efficacité des opérations. Les tendances dans les autres secteurs industriels et des ressources auront une incidence sur la capacité des collectivités à s'adapter au dendroctone du pin ponderosa pour le secteur forestier.

- Les pinèdes des zones boréales et de l'Est apportent à la société des avantages non reliés au bois. En raison de la taille relativement petite du secteur forestier dans la région des Prairies, les incidences des dommages causés par le dendroctone du pin ponderosa au chapitre des valeurs non reliées au bois pourraient avoir une plus grande importance dans cette région qu'en Colombie-Britannique. À certains endroits, les interventions sylvicoles peuvent être incompatibles avec ces valeurs. L'enlèvement des pins morts debout là où leur présence est incompatible avec d'autres valeurs (p. ex., les préoccupations en matière de sécurité dans les terrains de camping publics) peut aussi avoir des incidences financières.

- Des risques d'incendie supplémentaires et une incertitude accrue en ce qui concerne le comportement futur des incendies résulteront des dommages causés.

- Ne rien faire contre l'incursion du dendroctone du pin ponderosa excéderait la tolérance au risque des parties intéressées dans les régions menacées. Une réaction fondée sur les connaissances et les renseignements courants devrait comprendre un contrôle direct à court terme et une gestion préventive à plus long terme. Une réponse complète exigera un éventail de mesures de gestion fondées sur des objectifs qui correspondront aux conditions locales de pullulation, à la vulnérabilité des peuplements, aux valeurs menacées et à la faisabilité opérationnelle.

- L'incertitude quant à l'efficacité des mesures de gestion prises pour contrer les risques que pose le dendroctone du pin ponderosa peut être réduite en comblant les lacunes au plan de l'information que soulève ce rapport. Cela inclut le peaufinage des méthodes utilisées pour la surveillance et la détection de cet insecte et de meilleurs renseignements sur le couvert actuel dans les secteurs où il n'y a pas d'inventaire d'aménagement forestier. Le besoin immédiat d'information le plus crucial exige une surveillance et une détection efficaces de l'insecte dans les secteurs vulnérables à l'infestation actuelle. Les priorités en matière de recherche comprennent l'amélioration des connaissances sur la vulnérabilité des autres essences de pin au dendroctone du pin ponderosa et aux champignons qui lui sont associés, sur la compatibilité climatique ainsi que sur les modèles et les outils nécessaires pour prédire la dispersion de cet insecte, le comportement des incendies et les incidences économiques. Elles comprennent aussi les stratégies d'adaptation des collectivités.

1. Introduction

The mountain pine beetle *(Dendroctonus ponderosae* Hopkins*)* is the most destructive insect pest of mature pine forests in western North America (Safranyik and Carroll 2006). Periodic eruptions of populations cause widespread mortality, especially to lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) The recent outbreak in British Columbia began in the late 1990s. By 2006, nearly 10 million ha of pine forests had some level of tree mortality and an estimated 582 million m^3 of timber had been lost.

In the past few years, new infestations have appeared further north and east in British Columbia and Alberta, outside the historical recorded range of the mountain pine beetle. These new infestations are thought to be the result of migration of beetles from outbreaks west of the continental divide into areas east of the divide where there are suitable hosts for attack. Survival of broods has been favoured by a series of mild winters. This combination of available hosts and favourable weather has been observed in the past in the southern Canadian prairies. The current situation is novel, however, in that these new, more northerly areas of attack are not the isolated pine stands of southern Alberta but part of a relatively contiguous pine forest which extends across the boreal zone. Consequently, there is the potential for a native, western insect pest to become invasive outside its historic geographic range within Canada and attack pine species to which it has not been exposed previously. This leads to the question, "Is the mountain pine beetle a threat to the boreal and eastern pines forests of Canada?" If so, management response objectives and strategies must be considered.

This question of mountain pine beetle management comes as the Canadian Forest Service (CFS) and provincial governments are engaged in an initiative from the Canadian Council of Forest Ministers to develop a National Forest Pest Strategy. The accepted framework for the National Forest Pest Strategy is the application of risk analysis to forest pest problems. Risk analysis is a multidisciplinary approach to informing policy decisions. It is comprised of: 1) risk assessment, the use of evidence to estimate the likelihood and consequences of potential damage; 2) risk response, identification of options for reducing damage; and 3) risk communication, an interactive dialogue among stakeholders. This risk analysis framework was applied to the question of the threat of mountain pine beetle to the boreal and eastern pine forests

Two workshops, organized by the CFS, were held in August and September, 2007. Participants were drawn from the CFS and the British Columbia and Alberta forest services (a list of partipants is presented in the front-matter of this report). Given the urgency and complexity of the situation in 2007, participants agreed their objective was not to undertake a full risk analysis at this time but to provide the underlying risk assessment — the scientific and economic basis for overall management of risk. It is intended to support decision makers and provide advice to jurisdictions in responding to the mountain pine beetle.

The knowledge basis for this risk assessment was derived from facilitated, roundtable discussions among experts. A summary of these discussions was then presented as a list of statements with associated, available evidence and a consensus estimate of the uncertainty of this evidence. Ratings varied from low uncertainty, when there were multiple sources of independent observation or analysis meeting acceptable scientific criteria, to moderately high uncertainty, when such evidence was unavailable, preliminary or contentious. No attempt was made to assign a number to these uncertainties and then calculate an overall rating, as is characteristic of some risk assessments. Rather, these uncertainties are expressed explicitly with the reasons for the ratings, and are used to identify the information needed to further reduce uncertainty.

2. Nature of the Threat

Canada's pine forests are a rich and extensive natural endowment. Dominant native pine species include lodgepole pine in the west (including the western boreal), and jack pine (*P. banksiana* Lamb.), eastern white pine (*P. strobus* L.) and red pine (*P. resinosa* Ait.) in boreal and eastern forests. Pines occur in both pure stands and in mixtures with other tree species and so support diverse wildlife and vegetation. They provide a wide range of social, ecological and economic benefits to society. In total, pine-leading stands cover at least[1] 35 million ha and contain some 4.6 billion m^3 of standing volume in Canada (Tables I25 and I26 in Power and Gillis 2006).

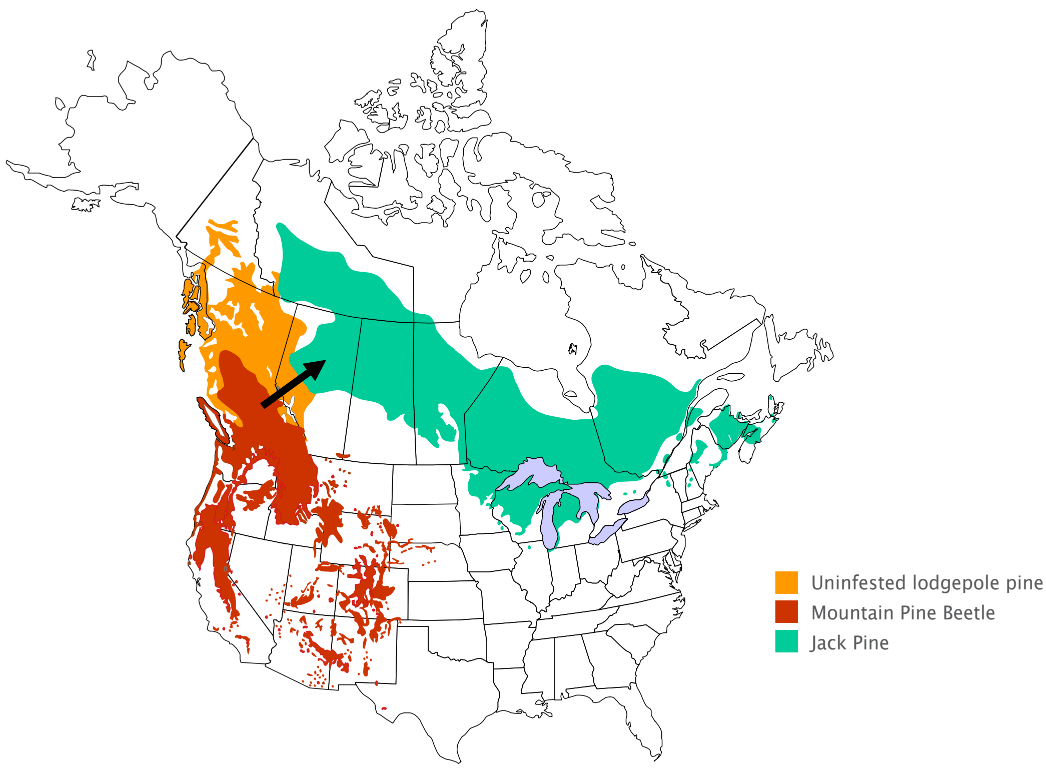

Figure 1. The mountain pine beetle has spread east of the Rockies to an area that forms a bridge between western and eastern pine forests in Canada. (Source: A. Carroll, CFS, Victoria BC)

Lodgepole pine is the host tree species most closely associated with mountain pine beetle in western Canada. However, the insect is known to attack and reproduce in several other pine species, including jack pine, which is distributed widely across Canada's boreal and sub-boreal forests. In the following two sections, evidence is presented on the threat posed to pine forests outside the range historically occupied by mountain pine beetle and the potential impacts of this spread.

[1] Actual area and volumes are likely higher due to additional pine stands within the "unclassified" and "unspecified conifer" categories, as well as areas that are not classed as "stocked forest".

2.1 Likelihood of range expansion

A. There has been a recent change in the geographic range of mountain pine beetle in Canada. Mountain pine beetle has invaded a susceptible portion of the Boreal Plains ecoregion.

EVIDENCE

The historic range of mountain pine beetle infestations in Canada before 2000 was restricted to pine forests west of the continental divide (with occasional exceptions as noted below) and south of approximately 56º N (Taylor et al. 2006; Figure 2). Within this range, mountain pine beetle occurred at elevations between 800 m to 1400 m. The apparent absence of records in the Pacific Maritime zone outside of Vancouver Island may represent the absence of surveys rather than the absence of mountain pine beetle, as well as the relative scarcity of pine species to support an evident outbreak in this maritime ecozone.

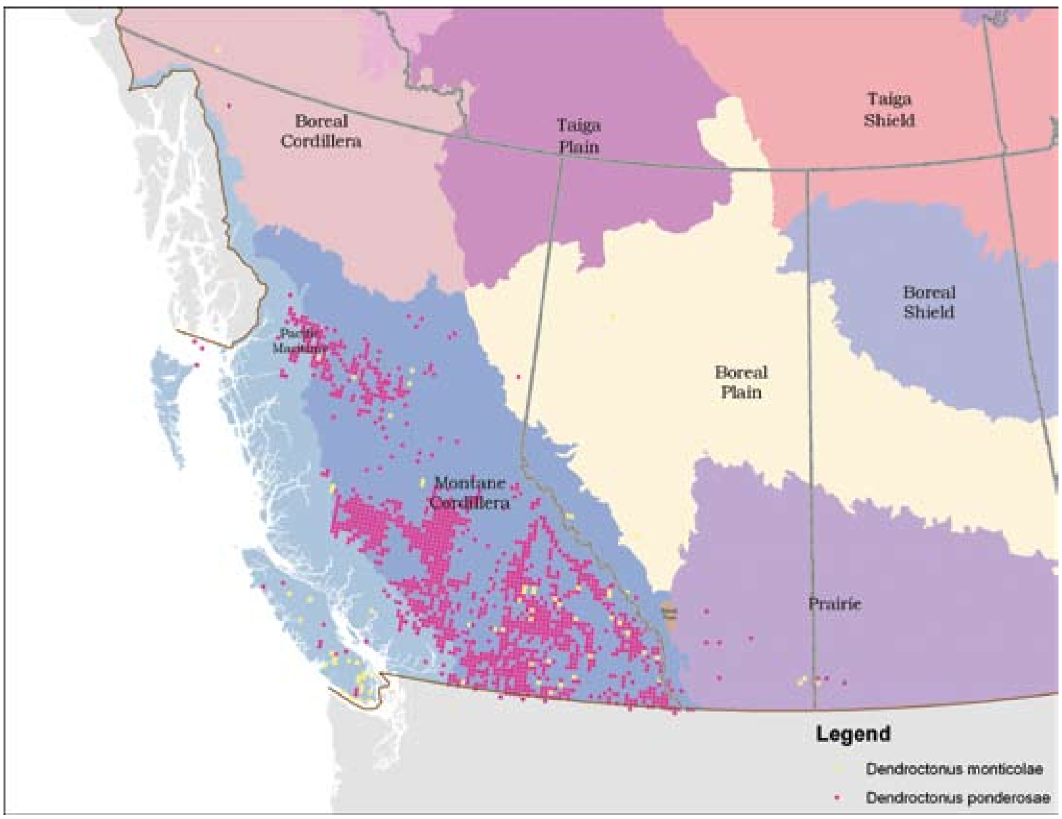

Figure 2. The observed range of the mountain pine beetle in western Canada in 1995.
(Source: FIDS Infobase records mapped by K. Porter and I. DeMerchant)

This historic range of mountain pine beetle did not extend as far north or east as the biological range of its principal host, lodgepole pine (Farrar 1995; Taylor and Erikson 2007) and so the range of the insect appeared more limited by climate than by host availability: historic outbreaks have been confined to an area south of the –40ºC isocline as this temperature kills the overwintering beetle population (Safranyik and Carroll 2006). The high-elevation, alpine conditions of the Rocky Mountains provided a similar climatic barrier to eastern expansion of the mountain pine beetle's range.

Damaging outbreaks of the mountain pine beetle have occurred throughout this historic range, although by far the most extensive have been recorded since the 1980s and especially since 2000 (Taylor et al. 2006; Taylor and Erikson 2007). Isolated infestations outside this main area have occurred in southwestern Alberta and eastward to the Cypress Hills on the Alberta–Saskatchewan border following outbreaks in the historic range immediately to the south and west. Outbreaks in these isolated satellite populations on the prairies typically did not persist following decline of mountain pine beetle populations in the source areas, but populations have persisted in the Cypress Hills, as well as the Alberta–British Columbia border area south of the Bow River, where populations have recently resurged (Figure 3; CFS [various years]).

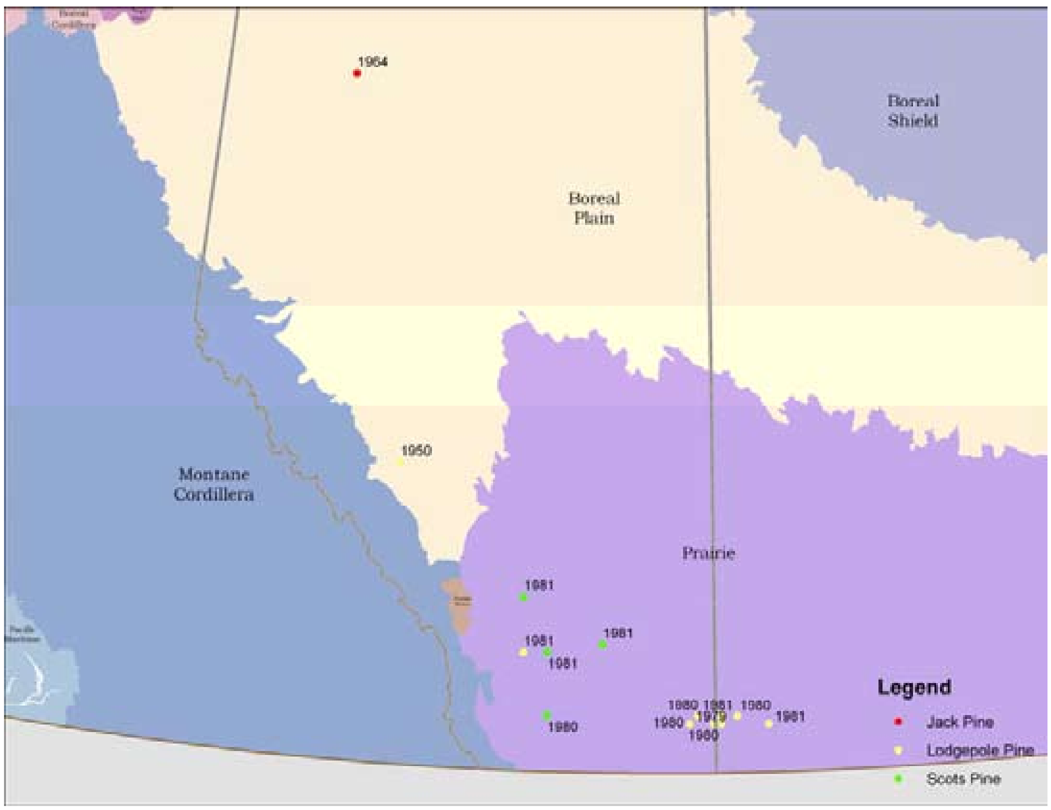

Figure 3. Locations where mountain pine beetle has been detected outside of its historic range. (Source: FIDS Infobase records mapped by K. Porter and I. DeMerchant.)

Beginning in the late 1990s, the area of mountain pine beetle outbreaks increased in British Columbia. By 2000, it was evident that populations of the insect were extending beyond the historic northern and eastern boundaries of the range (BCMFR 2007a) and incursions through the Rocky Mountains into Alberta were occurring (ASRD 2007a).

In 2006, evidence of spot infestations appeared in the British Columbia–Alberta border area north of Jasper National Park, extending north of the Peace River and eastwards to Lesser Slave Lake (ASRD 2007a). The wide distribution of these spot infestations and numerous observations of dispersing adult beetles implicated long-distance dispersal of mountain pine beetle from high-density source populations to the west as had happened during previous outbreaks. Figure 4 illustrates the known extent of these populations in 2007.

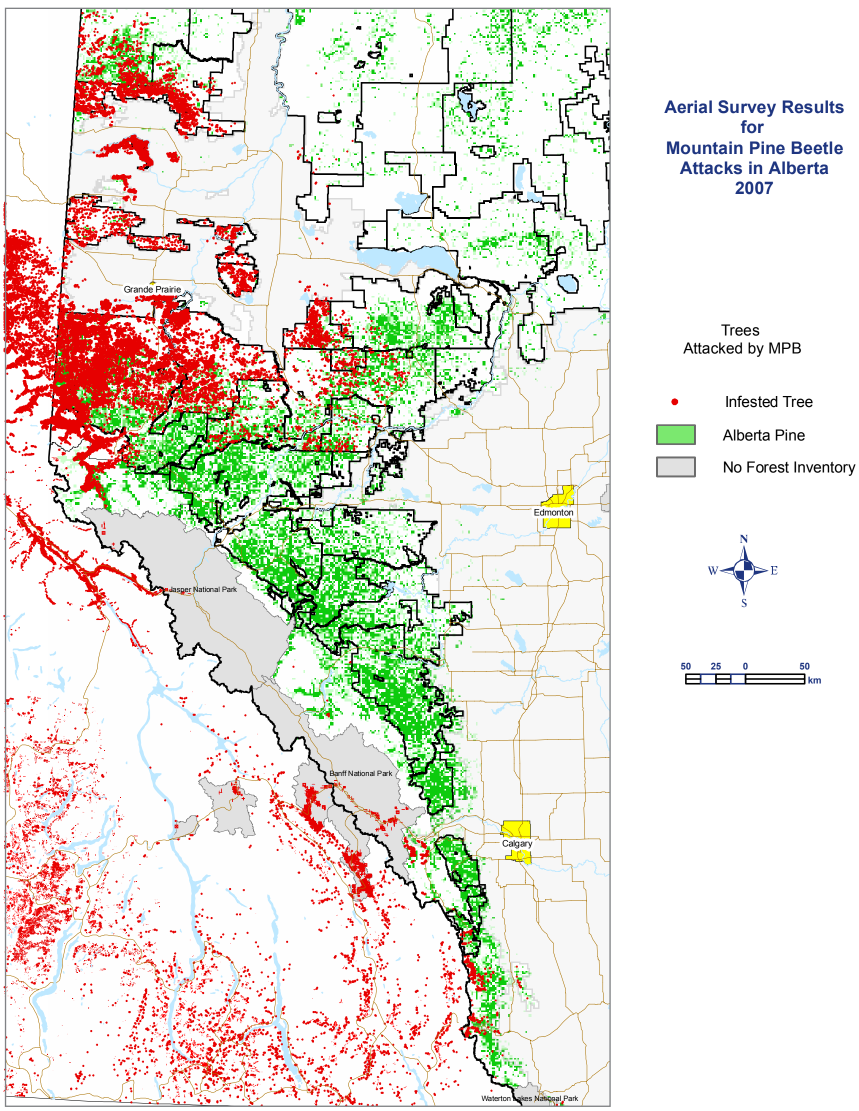

Figure 4. Aerial survey results for mountain pine beetle attacks in Alberta 2007.
Source: ASRD (2007a)

UNCERTAINTY

1) Very low uncertainty on known historic range as it is supported by years of repeated surveys.

2) Moderately low uncertainty on extent of expanded range because of incomplete and/or unconfirmed survey reports.

3) Moderately high uncertainty on long-distance dispersal as the mechanism of spread as only circumstantial evidence is available.

INFORMATION NEEDS

1) More extensive monitoring to track and confirm recent changes in distribution.

2) More sensitive methods to detect endemic populations and incipient epidemics.

3) Evaluation of persistence of previous spot infestations in the expanded range.

B. The mountain pine beetle can successfully attack and reproduce within a wide range of host pine species, including jack pine. There are therefore no known biological impediments to the spread and establishment of the mountain pine beetle through the boreal zone.

EVIDENCE

Within Canada, the mountain pine beetle is almost exclusively associated with lodgepole pine but potential hosts include most pine species within its geographic range (Furniss and Carolin 1977). Successful attack and brood production also has been observed in several pine species and even in spruce (*Picea*) occurring outside the mountain pine beetle's historic range, including several independent observations on jack pine (Furniss and Schenk 1969; Safranyik and Linton 1982; but see Cerezke 1995). Measures of performance of mountain pine beetle (i.e. rate of successful attack, brood survival, fecundity) in jack pine and lodgepole–jack pine hybrids indicate their suitability is comparable to lodgepole pine (Safranyik and Linton 1982). Recent experimental studies confirm these results (D. Langor, Canadian Forest Service, Edmonton, AB, personal communication, August 2007). Equally significant is the ability of the ophiostomoid fungi associated with the mountain pine beetle to colonize and spread successfully in living jack pine (Rice et al. 2007a, b).

UNCERTAINTY

1) Moderately low uncertainty on suitability of other pines, especially jack pine. There are always questions when host suitability is measured in artificial circumstances (i.e. cut logs or trees planted off site). The number of beetles required to overcome host-tree defences could differ in jack pine compared to lodgepole.

2) Moderate uncertainty in the extent to which this host susceptibility will change as a result of expected climate change.

INFORMATION NEEDS

1) Neither primary nor secondary defensive reactions of jack pine *in situ* have been investigated. There is a need to assess the range of variation in intrinsic resistance capacity of jack pine phenotypes and genotypes and to assess variability in resistance in the climatic and edaphic conditions of the boreal zone.

2) Improved understanding of the potential diversity and pathology of associated fungal strains that may be introduced with mountain pine beetle or acquired by it in its new environment.

3) Studies of the susceptibility of other pines (e.g., eastern white pine and red pine) to beetle attack and associated fungi would decrease uncertainty of risks to pine stands further east.

C. The structure of host pine stands in the boreal zone is suboptimal for the mountain pine beetle as pine stands in the boreal are less contiguous, younger and have lower relative volumes than do pine stands in British Columbia.

EVIDENCE

The structure of pine stands with susceptible hosts is a key factor in the epidemiology of mountain pine beetle (Safranyik and Carroll 2006). At a given level of individual tree susceptibility, epidemic populations occur in stands with a high proportion of old, large trees (Shore and Safranyik 1992). Available forestry data indicate that the distribution of these susceptible stand types (as distinct from susceptible tree species) is more fragmented in the pine forests of the northern boreal compared with those in British Columbia or along the foothills of Alberta (Figure 5).

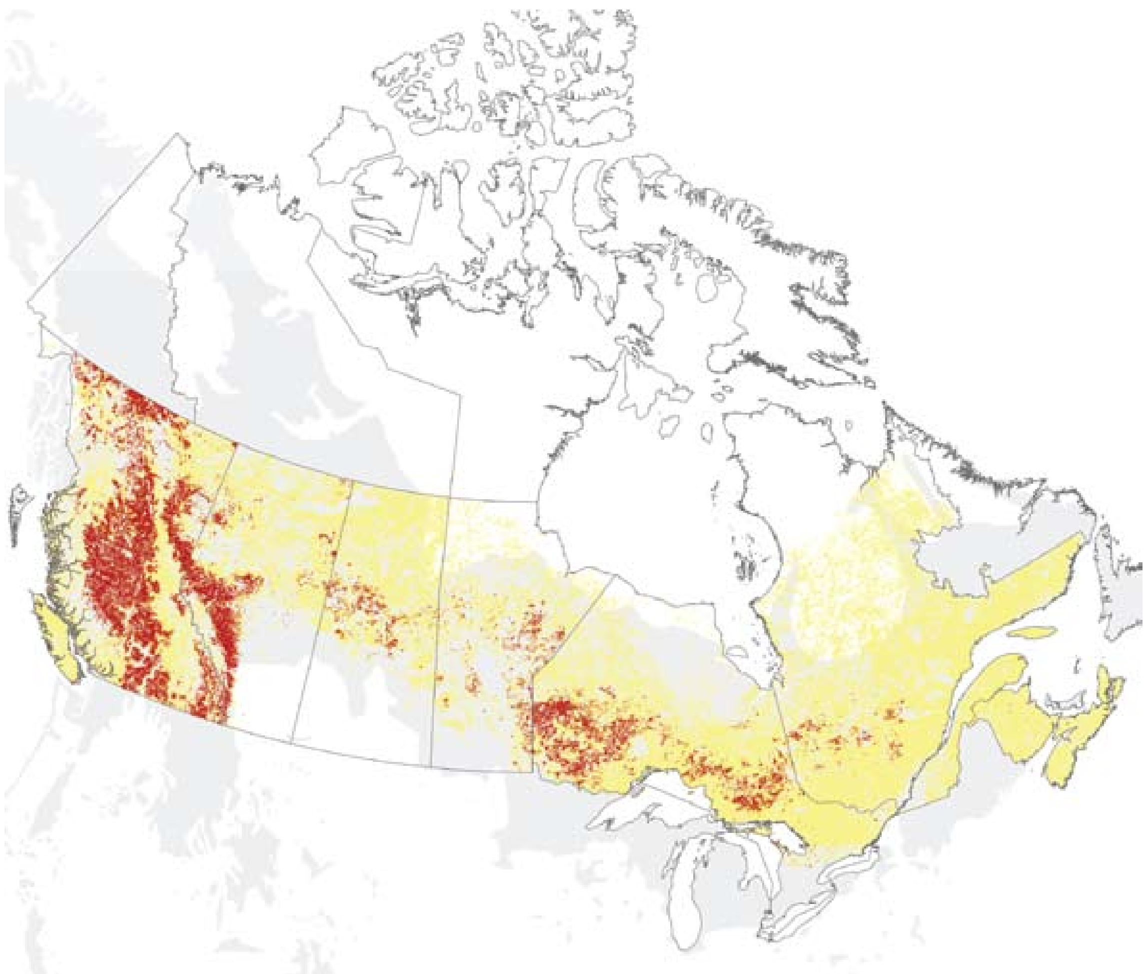

Figure 5. Pine stands in Canada where stand volume exceeds 40 m^3/ha are shown in red. At a given level of susceptibility of individual pine trees, such stands are much more susceptible. Yellow areas have less than 40 m^3/ha of pine. (Source: Yemshanov, D., McKenney, D.W., Pedlar, J.H. unpublished results of host distribution research based on Canadian Forest Inventory and EOSD data).

This difference between lodgepole pine forests of British Columbia and western Alberta and jack pine forests of the boreal is the result, in part, of regional differences in climate and soils. Also, patterns of anthropogenic disturbance history such as fire suppression and selective logging that pre-disposed lodgepole pine forests in the last half of the 20th century to severe outbreaks in British Columbia (Taylor et al. 2006), have been relatively rare in most areas of the boreal zone, particularly in Saskatchewan. These differences suggest that growth and spread of mountain pine beetle populations may be significantly lower in the boreal forest compared to that observed in British Columbia and western Alberta.

UNCERTAINTY

1) Moderate to high uncertainty as information on forests with respect to questions of forest structure is insufficient in detail and coverage. Data from Canada's National Forest Inventory and the Earth Observation for Sustainable Development program provide relatively (but not absolutely) complete coverage, but the resolution is coarse, and critical details such as current age and volumes varies. Forest cover maps from inventories are more reliable in terms of these details but lack complete coverage and are often not accessible or are outdated (Figure 6).

2) Moderate uncertainty exists in applying parameters that estimate the relationship between forest conditions and outbreaks in British Columbia forests to the distinct forest conditions in the boreal zone.

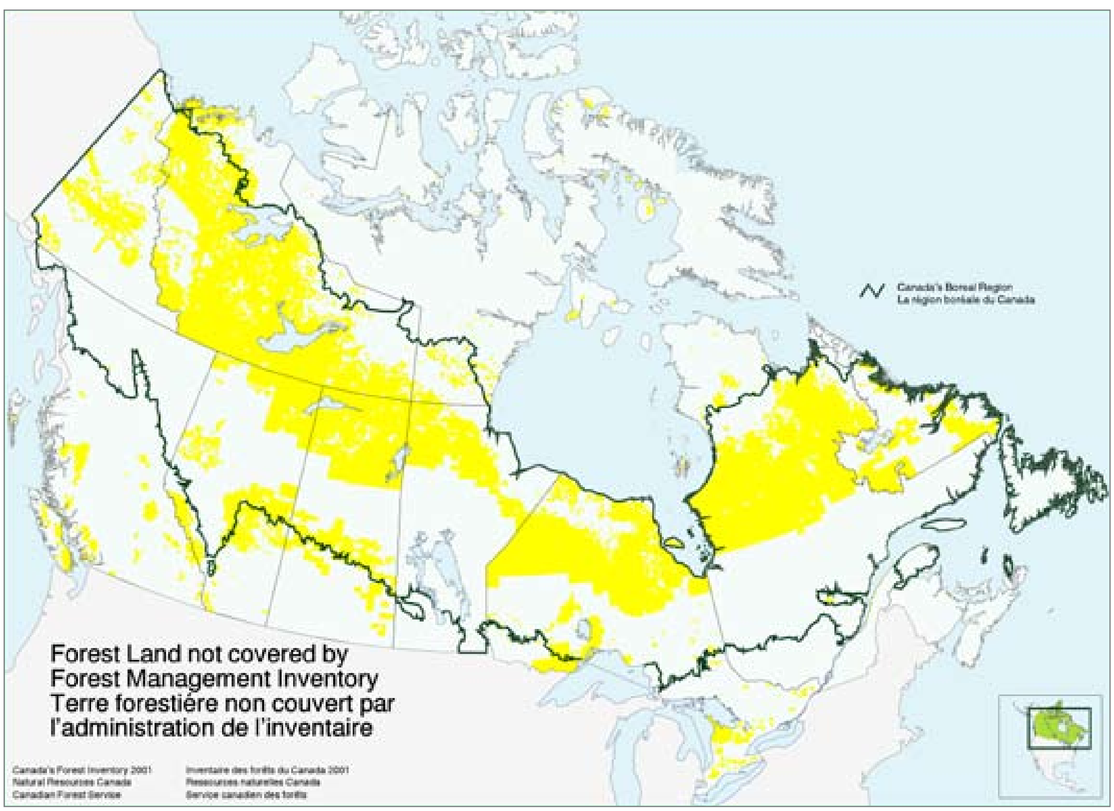

Figure 6. Areas of Canada not covered by a forest management inventory.
(Source: CanFI database; M. Gillis)

INFORMATION NEEDS

Better inventory information is needed throughout the forested areas of immediate interest to this assessment including forest cover in parks, federal and private lands, and marginally productive forests (Map 9, Appendix 2). The lack of inventory does not mean the lack of ecologically suitable habitat for mountain pine beetle. Although the existence of detailed forest inventories in such areas would benefit this assessment, the expense of establishing and maintaining these is likely prohibitive in areas where they are not required for normal operations basis. As such, new approaches to providing a higher level of detail in these areas in a cost-effective way will have considerable value to future assessments of this kind (e.g., Gillis et al. 2005).

D. There are no major differences in the competitors or natural enemies of the mountain pine beetle in the jack pine and lodgepole pine forests of Canada

EVIDENCE

The transition from endemic to incipient outbreak phases of mountain pine beetle is influenced by interspecific competition among other bark-feeding insects in the habitat (Safranyik and Carroll 2006). These major competitors of mountain pine beetle appear common to lodgepole and jack pine communities in Canada (Bright 1976). Similarly, the natural enemies (parasitoids, pathogens, predators) associated with mountain pine beetle in lodgepole pine forests in British Columbia are common throughout the boreal zone (D. Langor, Canadian Forest Service, Edmonton, AB, personal communication, August 2007).

UNCERTAINTY

1) Low uncertainty on the similarity of the composition of the competitor–natural enemy faunas in lodgepole and jack pine forests. Therefore, the expected qualitative nature of interactions in both forest types is comparable.

2) Moderate uncertainty on the quantitative nature of these interactions as they pertain to mountain pine beetle dynamics.

INFORMATION NEEDS

1) Better understanding of the relationship between the intensity of competitor interactions and host condition in the transition from endemic to incipient population phases in both lodgepole and jack pine hosts.

2) Better quantitative estimates of attack rates by major predators and incidence of diseases over the range of mountain pine beetle densities.

E. Current climatic suitability for mountain pine beetle is greatest in central British Columbia and the foothills of the Rocky Mountains. Suitability is moderate in central Alberta to Saskatchewan and decreases eastward to northern Ontario where climate suitability for mountain pine beetle is low.

EVIDENCE

Climate characteristics of areas suitable for the successful establishment, persistence and potential outbreak of mountain pine beetle populations have been derived from historic data (Safranyik et al. 1975). These factors have been compiled in various models to examine the role of climate in present and future outbreaks (Taylor et al. 2006). Additional models have been developed based on measurement of temperature-dependent physiological processes such as development (Bentz et al. 1991; Logan and Powell 2001) and cold tolerance (Régnière and Bentz 2007). Each of these models was run under BioSIM, a simulation environment that integrates biological models with climate and weather data to produce maps of weather-driven target events across a landscape over time (Régnière 1996). For this risk assessment, two series of maps representing BioSIM outputs of three distinct models and their composite (a geometric mean) were produced (Figure 7). One series used recorded climate normals from the four nearest weather stations to each of 20,000 simulation points across Canada for the period 1971-2000 to produce a background simulation of climate suitability during the development of the current outbreak. The second series of maps was produced from climate-changed normals for the period 2001-2030 using the daily output of CGCM-1 (Canadian General Climate Model-1), with an annual 1% CO_2 increase starting in 2000. The composite maps were constructed from the geometric mean (cube root of the product of the output probabilities from each of the three models (J. Régnière, Canadian Forest Service, Québec City, PQ, personal communication, October, 2007).

The result shows climatic suitability has been very high in the area of recent, catastrophic outbreaks in central British Columbia and in the Alberta foothills. Current climatic suitability is moderately high throughout central Alberta into Saskatchewan and declines eastward. There are isolated zones of suitability in southern Ontario, eastern Quebec, and Newfoundland.

In the near future, the area of climatic suitability will actually increase in British Columbia and northwestern Alberta, especially northward toward the Yukon and North West Territories putting these areas at greater risk to mountain pine beetle. By comparison, the area of climatic suitability in the more easterly portions of the boreal zone will decrease slightly and shift northward (Figure 7).

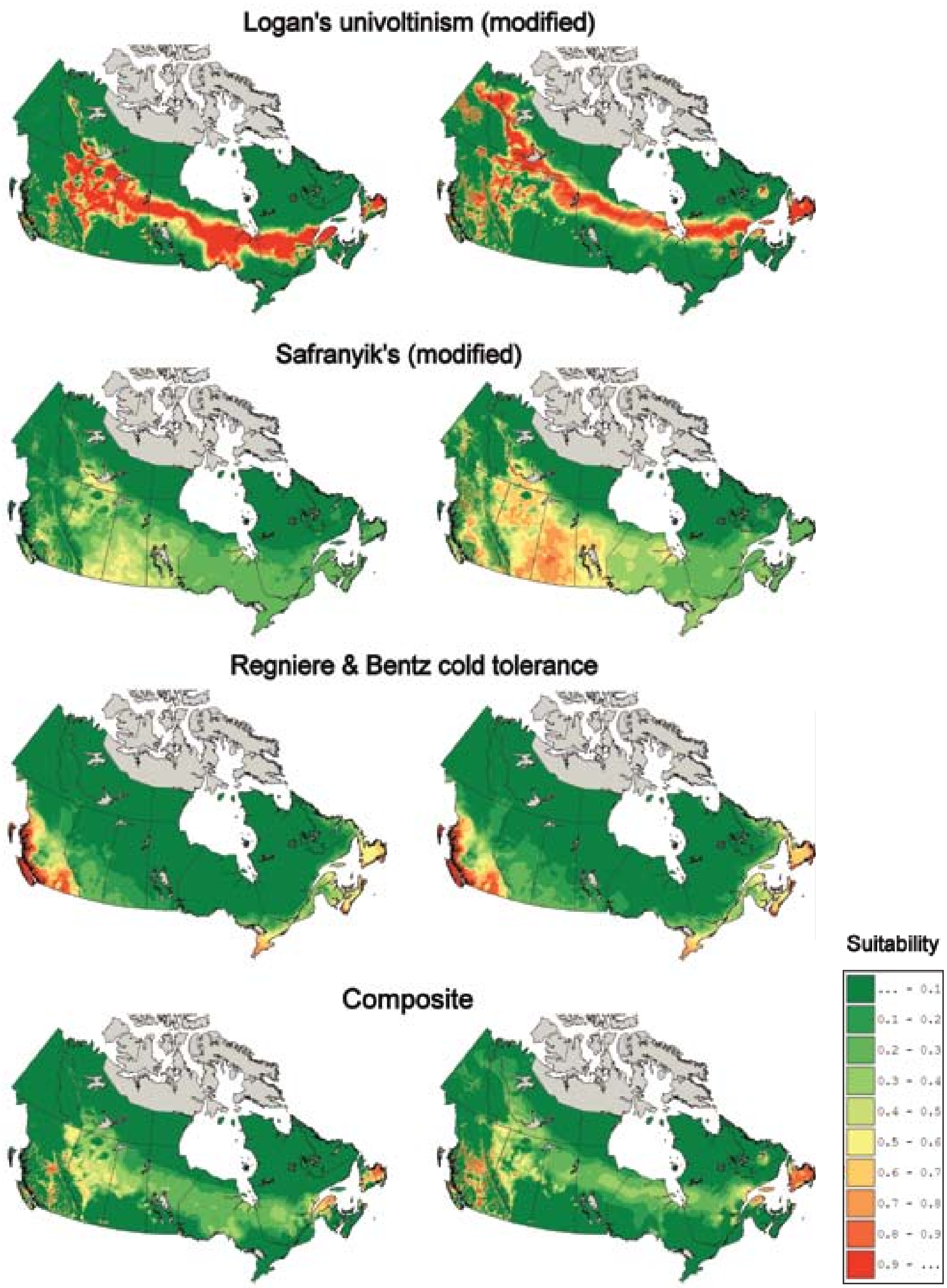

Figure 7.Climatic suitability for mountain pine beetle in Canada according to three models and their composite for climate data using observed normals, 1971-2000 and climate-change estimates 2001-2030.

UNCERTAINTY

1) Moderate uncertainty results from the premise that a predominately univoltine[2] seasonality is necessary for outbreaks to develop. A distinction could be made between populations that are usually univoltine (as determined by use of normal temperature records) and populations that become univoltine for a sufficient period of specific climatic conditions to permit population increase such as occurred in central British Columbia in the mid- to late-1990s.

2) Low to moderate uncertainty exists as to whether the influence of drought in the British Columbia model in lodgepole pine will be similar when applied to jack pine in the boreal forest.

3) Low to moderate uncertainty results from the absence of spatial variability in development-rate parameters in mountain pine beetle populations explicit in the phenological models used in the simulations (Bentz et al. 2001).

4) Moderate uncertainty surrounds climate change and the use of simulated series of daily weather from normal (average) conditions, as details of actual future daily weather sequences are obviously unknown.

5) Low to moderate uncertainty exists on the realism of the geometric mean of three model outputs as a scheme to obtain the composite probability maps.

INFORMATION NEEDS

1) Field assessment of the importance of a univoltine condition on generation survival over a range of climatic conditions.

2) Comparison of climatic patterns corresponding to drought stress in lodgepole pine in British Columbia with jack pine in Alberta.

3) Comparison of temperature-dependent growth and survival parameters among populations over a latitudinal gradient.

4) More biologically realistic integration of the three models (development, tree resistance through drought stress, and overwinter mortality).

[2] Refers to beetle populations that have one generation per year (Safranyik and Carroll 2006).

F. Current climate suitability decreases east of Saskatchewan but the susceptibility of the forest increases.

EVIDENCE

Available climatic models and forest-cover data support this statement. Although the overall risk of severe outbreaks such as those observed in British Columbia is less in the boreal zone, the risk is considerably greater than zero. Moreover, occupation of the boreal zone by the mountain pine beetle would represent range expansion. This would increase the risk of development of a pathway in which future resident populations of mountain pine beetle in the boreal plain expand into more susceptible pine forests of central Canada.

UNCERTAINTY

1) Low uncertainty exists around the non-zero and potential threats to pine forests east of the current outbreaks.

2) Moderate uncertainty exists as to the time scale over which that threat will develop.

G. The potential rate of spread of mountain pine beetle can be estimated. The dynamic behaviour of beetles on an invasion front will not differ from observed behaviour in similar situations within historic range of the insect.

EVIDENCE

Two qualitatively different modes of dispersal by adult mountain pine beetle contribute to observed spread: normative, short-range dispersal away from their natal tree to attack new trees within the stand; and long-distance dispersal of adults above the canopy to new stands. The short-range dispersal process is relatively well-studied and results in a generally downwind, diffusive pattern of spread (Safranyik and Carroll 2006) to create an ever-expanding pattern of outbreak with red, recently attacked trees along the front and grey, dead trees in its wake. The rate of this spread is a function of local mountain pine beetle density and known stand-level parameters affecting dispersal including micro-climatic parameters (Safranyik and Carroll 2006; Whitehead et al. 2006). The rate can be estimated by direct observation of the spatial distribution of new and old attacks. There is no reason to expect that such estimated rates of spread will differ given the same conditions elsewhere.

Long-range dispersal of adult mountain pine beetle, by comparison, is very difficult to characterize. One could logically posit that a combination of high beetle density and suitable weather conditions (i.e., advective air movement) at the time of adult beetle flight would strongly influence the process. However, the distance of this movement and location of resulting attacks will remain difficult to predict. Unlike other well-known outbreak species such as spruce budworm and locusts, the dispersal behaviour of mountain pine beetle makes long-distance, above-canopy dispersal an exceptional, rather than a normal, event in the epidemiology of outbreaks. It follows that although diffusive spread from existing outbreaks is certain; observations over the last half century suggest that major long-distance dispersal resulting in significant transport of populations occurs only when mountain pine beetle densities are extremely high.

UNCERTAINTY

1) Moderately low uncertainty exists on the role of beetle dispersal on observed epidemiology of outbreaks. Both short- and long-range mountain pine beetle dispersal is well-documented, but the estimated spread rates are based on observation of successfully attacked dead trees; i.e., estimates are indirect. Some contribution to eventual damage may also come from the transition of local populations from the undetected endemic phase to the epidemic phase. This occurs regularly in areas where conditions permit that local transition in phase behaviour.

2) Moderately high uncertainty exists on the role of long-range dispersal in outbreaks, as this contribution would normally be masked by other, more dominant processes contributing to the pattern of spread. Although the fact of long-distance dispersal and resulting local infestations has been established, the likelihood of these events resulting in sustained, outbreak populations is uncertain.

INFORMATION NEEDS

1) A process-level model of dispersal emphasizing the influence of stand characteristics on the rate and direction of spread would be invaluable for predicting range expansion and for identifying effective preventative actions.

2) Retrospective analysis of ecological and weather conditions associated with long-distance dispersal should be carried out using historical data and climatic models described in this assessment.

2.2 Consequences of range expansion

A. There is a finite risk to all pine forests but expected volume losses in the boreal forests of Alberta, Saskatchewan and Manitoba will be less than those experienced in British Columbia at all scales other than the tree level. Even under outbreak conditions, average stand-level losses in the boreal forest would be unlikely to exceed 30% of stems or 40% to 60% of standing volume.

EVIDENCE

Pine stands in the northern prairie and boreal regions are sparser and have lower volumes than those in British Columbia and adjacent Alberta (Figure 5). Consequently harvest rates in these areas are lower (Table 1). This forest structure influences the relative importance of the resource in the region and, as discussed above, is also likely to slow mountain pine beetle spread in the boreal region relative to spread rates in British Columbia. Under these conditions, average stand-level losses during an outbreak in the boreal region would be unlikely to exceed 30% of stems or 40% to 60% of standing volume (L. Safranyik, Canadian Forest Service, Victoria, BC, personal communication, September 2007).

Table 1. Annual forest harvest volumes by province. Source: CFS 2006a.

PROVINCE	Harvest volume (million m^3)
Alberta	23.5
British Columbia	87.0
Manitoba	2.1
New Brunswick	11.4
Newfoundland	2.3
Nova Scotia	6.9
Ontario	25.2
Prince Edward Island	0.7
Quebec	43.3
Saskatchewan	6.1

UNCERTAINTY

Moderate to low uncertainty as several independent sources of data (forest cover maps, data from the Earth Observation for Sustainable Development Program and Canada's Forest Inventory) indicate lower volumes of pine in boreal stands relative to pine stands in British Columbia.

INFORMATION NEEDS

Complete inventory-level assessments for areas at risk in Alberta and Saskatchewan.

B. Compared to the British Columbia interior, boreal forests contain a high proportion of low-volume stands already close to the margins of operability for commercial timber harvesting. Mountain pine beetle-related impacts therefore pose a high risk to the operability of these stands.

EVIDENCE

A high proportion of pine stands in the boreal forest across eastern Alberta, Saskatchewan, and Manitoba have stand volumes of less than 40 m^3/ha (Figure 5). Although many factors determine stand operability (e.g., access and harvest costs, other forest management costs, wood quality, market conditions, social and ecological constraints), stands with lower volume have less capacity to absorb losses (volume and quality) while remaining operable. Even moderate damage from mountain pine beetle, therefore, poses a high economic risk to the operability of such stands.

UNCERTAINTY

Moderate uncertainty exists. Lower volumes are known to be characteristic of boreal forests. However, shifts in forest product markets or harvesting and processing costs can change operability thresholds.

C. Communities are vulnerable to socioeconomic impacts resulting from the mountain pine beetle. Timber supply in some regions may not have the capacity to accommodate mountain pine beetle-related losses. However, the current state of other industries (such as oil and gas) relative to the forest sector may improve the adaptive capacity of some communities.

EVIDENCE

The socioeconomic impact of mountain pine beetle in an expanded range will vary with local circumstances. Phillips et al. (2007) analysed the potential impact of mountain pine beetle on timber supply in Alberta's Foothills Model Forest and found that impact will depend on rates of spread of the beetle. A relatively slow spread could be accommodated within existing rates of harvest but faster rates of spread would result in accelerated harvest to minimize losses from decay, followed by reduced harvesting. These variables are further influenced by the age-class structure and species composition of the forest as well as practical limitations imposed by local processing capacity, labour, and future markets for products made from beetle-affected wood.

The magnitude of consequences for communities depends on local reliance on the forest sector and trends in other sectors of the economy. In 2001, the forest sector in the boreal region generated an estimated 58,200 jobs and $2.4 billion in labour income, accounting for approximately 3.5% of jobs in the region and 6% of overall labour income (Patriquin et al. 2007). These figures, however, may not be sustained irrespective of the risk of mountain pine beetle as recent employment growth in the region has come mainly from other sectors such as energy and hospitality and overall forest-sector employment has declined (Patriquin et al. 2007). Since 2001, Canada's forest sector has struggled as a result of several factors including high cost of operations, weakening U.S. demand, strength of the Canadian dollar, and export taxes on U.S.-bound shipments (FPAC 2007). Although some of these factors may be cyclical in nature (e.g., U.S. demand), the ongoing boom in other commodity sectors, such as energy and mining, will likely further reduce the relative importance of the forest sector, particularly in the prairie region. In fact, labour shortages caused by the abundance of well-paid jobs in other resource industries (especially in Alberta) are seen as a constraint to some sectors that have capacity for further growth (Hirsch 2006). Where this is the case, the adaptive capacity of communities to potential impacts from the mountain pine beetle has likely improved.

Preliminary results from a regional economic impact analysis of mountain pine beetle in British Columbia show that economic diversity plays a large role in determining the magnitude of local impacts when shifts in forest sector activity occur (Patriquin, M., B. Stennes, A. McBeath and W. White. 2007. *Regional Economic Impacts Resulting from the Mountain Pine Beetle and Provincial Policy Response.* Unpublished draft report, Canadian Forest Service, Natural Resources Canada). Impacts of mountain pine beetle are expected to be more moderate in diverse economies such as Kamloops, British Columbia, for example, than in more forest-dependent communities. A recent report (BCMFR 2007b) also confirms the resilience of more diverse economies and expects that many skills acquired in the forest industry will be readily transferred to other expanding industries in the energy sector.

UNCERTAINTY

Uncertainty is moderate to high. The net impact of mountain pine beetle on forest-dependent communities depends on the timing and severity of the damage. Economic consequences are uncertain even where impacts are already evident. By the time timber supply is reduced outside British Columbia, the forest sector may already be contributing less to local economies. Furthermore, other sectors such as oil and gas may be in a completely different state (larger or smaller) than at present (2007).

INFORMATION NEEDS

Use of mountain pine beetle-affected timber in the current lumber and pulp sectors has been well studied in British Columbia and this information can be applied to the boreal region. The economic consequences to specific communities after the beetle has changed the character, abundance and location of timber supplies are less clear and potential strategies require research. Research on options such as bioenergy production and use, plantation fibre strategies, value-added possibilities for remaining fibre supply, post-epidemic forecasts of mill locations, markets served, etc should be considered.

D. Non-timber impacts will have a greater relative significance in the prairie region than in British Columbia. Forest management interventions may come into conflict with non-timber values.

EVIDENCE

Boreal and eastern pine stands are a rich source of non-timber revenue from tourism, recreation, and trapping. Forests provide many social and ecological benefits such as water conservation and quality, urban amenities, wind-breaks, carbon storage, wildlife habitat, and traditional uses. These values vary widely by location, but are significant to all provinces and territories. An Environment Canada (2000) study of the economic significance of nature-related activities[3] in Canada provides clear evidence of this in both absolute and per capita terms (Table 2).

Table 2. GDP from nature-related activities for Canada, the provinces, and the Yukon.

AREA	GDP	
	Total (million $)	Per capita ($)
Alberta	1567.2	623.52
British Columbia	1828.3	557.06
Manitoba	405.5	371.36
New Brunswick	193.0	266.61
Newfoundland	156.7	275.65
Nova Scotia	242.3	269.24
Ontario	4522.4	448.43
Prince Edward Island	26.5	204.22
Quebec	2318.4	336.20
Saskatchewan	374.1	378.29
Yukon Territory	11.7	420.91
Canada		417.63

(Source: Environment Canada (2000). Per capita measures were estimated using population statistics from the 1996 census, which was the same year in which the Environment Canada nature survey was done).

The total estimated value of nature-related activities in terms of GDP contribution is highest in Ontario followed by Quebec, British Columbia, Alberta, Manitoba and Saskatchewan in order. The highest per capita GDP contribution from nature-related activities, however, is in the province at greatest risk from mountain pine beetle, Alberta, followed by British Columbia, Ontario, Yukon Territory, Saskatchewan, and Manitoba.

[3] Defined as "a recreational activity that includes, in some form, either direct or indirect contact with nature. Outdoor activity in natural areas, residential wildlife-related activity, wildlife viewing, recreational fishing, hunting and indirect nature-related activity are included in this category."

Combining these statistics with the employment estimates for the forest sector in the same year (CFS 1997) gives an index of the relative importance of nature-related activities. For example, in 1996, Saskatchewan had an estimated 1.6 jobs supported by nature-related activities for every job within the forest industry. In Alberta and Manitoba, this proportion was roughly 1:1. In British Columbia, the situation is reversed, with approximately three jobs in the forest industry for every job supported by nature-related activities (Figure 8). Thus, non-timber forest values are relatively more important to the job sector in the Prairie Provinces than elsewhere in Canada.

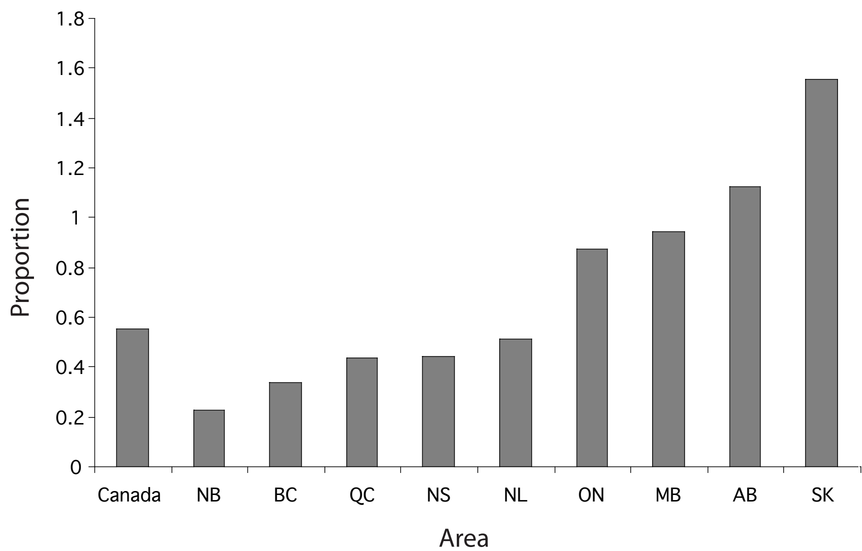

Figure 8. Jobs supported by nature-related activities as a proportion of direct jobs in the forest industry. (Source: Environment Canada (2000); CFS (1997)).

Information on the regional economic significance of trapping in Canada is also available (Statistics Canada 2007). In 2005, the value of wildlife pelts in Alberta, Saskatchewan and Manitoba was higher than in British Columbia (Figure 9).

The impact that increased mountain pine beetle activity in the boreal may have on trapping is difficult to assess. Modest mountain pine beetle mortality may actually benefit some commercial trapping species such as marten whereas more severe damage would likely have a negative impact (Chan-McLeod 2006). Mountain pine beetle attacks may degrade woodland caribou habitat by reducing lichen cover, a critical food source for these animals (Williston and Cichowski 2006).

Hydrological impacts from the reduction of live pine over-story may be significant (BCFPB 2007). Watershed concerns are a main factor currently driving Alberta's mountain pine beetle control efforts on the east slope of the Rockies (D. Lux, Alberta Sustainable Resource Development, Edmonton, AB, personal communication, November 2007).

The cost of disposing of dead-standing pine where its presence is incompatible with other values (e.g., safety concerns in public campgrounds) is an economic impact. Salvage harvesting may have more negative impacts than the disturbances themselves (Lindenmayer et al. 2004). Public perception of the threat posed by forest management interventions to non-timber values could lead to conflict as occurred in southern Alberta where forestry interests advocating accelerated harvest were opposed by those who felt that the industry could not be trusted in matters of conservation (Koch 2007).

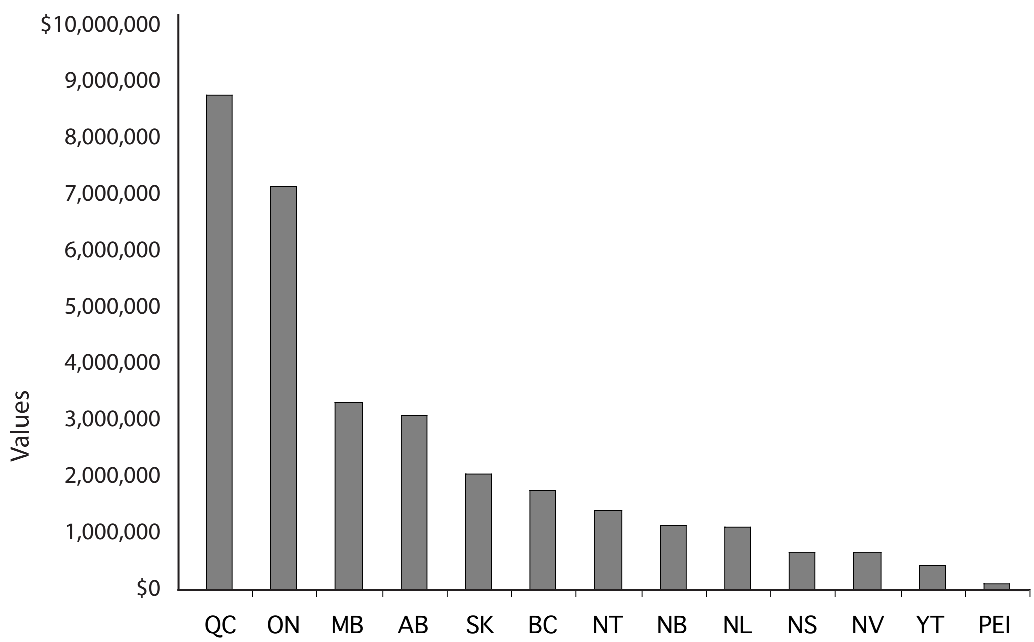

Figure 9. Value of wildlife pelts sold by province.
Source: Statistics Canada 2007.

In summary, the smaller scale of the forest sector in the prairie region means that negative impacts of mountain pine beetle on non-timber values will have a greater relative economic significance in this region than in British Columbia. Forest management interventions also may come into conflict with these values in certain locations.

UNCERTAINTY

Uncertainty is low because of the known relative values of timber v.s. non-timber values in the boreal region compared to British Columbia.

D. Some additional fire risk may result from mountain pine beetle impacts.

EVIDENCE

The large areas of dead pine that result from severe mountain pine beetle damage raises concern of future fire risks. Fire risk will be greatest while highly combustible dead needles remain on trees killed by the mountain pine beetle (2 to 3 years since attack[4]) then decline for 10 to 15 years until concentrated surface woody fuels from dead trees fall-down accumulate and again increase fire risk (B. Hawkes, Canadian Forest Service, Victoria, BC, personal communication, September 2007). This pattern of fuel dynamics was observed in Yellowstone National Park (Page and Jenkins 2007). Areas affected by mountain pine beetle in the mid-1970s were shown to have an 11% greater likelihood of burning as crown fires during the 1988 fire season in Yellowstone (Lynch et al. 2007).

Salvage harvesting itself increases the risk of fire because of resulting increased access for both industry and the public (Sterling Wood Group Inc. 2001). Dead pine may pose operational and safety challenges to fire crews, reducing overall suppression effectiveness (S. Taylor, Canadian Forest Service, Victoria, BC, personal communication, August 2007).

Despite these potential changes in fire risks associated with mountain pine beetle, senior fire managers in British Columbia feel that current strategies and capacity can deal with this change in risk (Rogers 2001). Although this conclusion was based on a more modest forecast of the mountain pine beetle outbreak extent than has been the case, the important point is that pine forests are fire-prone even in the absence of mountain pine beetle mortality (Taylor and Carroll 2004). Tree mortality may effectively widen the range of conditions under which crown fires can occur and may lengthen the annual fire season but fire risks in the boreal will not be a new phenomenon if mountain pine beetle activity spreads eastwards. While improvements to fire management in Canada may currently be needed, particularly with respect to the wildland–urban interface (CFS 2006b), this is a broader issue than incremental risks resulting specifically from mountain pine beetle activity. Climate change will be a greater driver of increased fire risk in the future (Wotton and Stocks 2006).

UNCERTAINTY

Uncertainty is high because of unknown extent of impacts and the questionable significance of any increased risk in a fire-prone ecozone exposed to climate change.

INFORMATION NEEDS

Research is needed to incorporate post-mountain pine beetle conditions into existing fire behaviour models (e.g., parameters such as percent mortality and time-since-kill) to better understand impacts on fire risk. Studies of burns in beetle-damaged stands are needed.

[4] The timing and magnitude of such risks will vary. For example, some stands may display high and uniform mortality, while in other stands, mortality will be spread over several years, limiting the abundance of dead needles but extending the period of time in which they are present.

E. Regulatory impacts or changes to fibre flows may result from mountain pine beetle activity.

EVIDENCE

In Alberta, stands killed by the mountain pine beetle are subject to a use-it-or-lose-it policy. Forest companies may have their cut re-directed if they cannot keep pace with the infestation http://www.qp.gov.ab.ca/documents/Acts/F22.cfm?frm_isbn=077974733X). Mountain pine beetle-related harvesting may also strain transportation infrastructure. Redirecting harvest to affected or vulnerable stands may lead to suboptimal harvest scheduling.

The mere presence of mountain pine beetle could also have regulatory impacts such as transportation restrictions. For example, Alberta currently restricts the import of conifer logs that may pose forest pest risks. The transportation, storage and processing of beetle-infested logs is also highly regulated within Alberta (ASRD 2007b). Such restrictions carry potential costs associated with decreased flexibility available to operators, as well as costs of establishing and implementing the regulations themselves. Transportation restrictions may limit future options for mountain pine beetle management or use of timber supply.

UNCERTAINTY

There is low uncertainty that there will be regulatory and fibre flow impacts but the specific impacts are highly uncertain.

3. RESPONSE

This section provides an overview of integrated response strategies to the threat of mountain pine beetle. It does not recommend site-specific operational actions as doing so requires stand-level assessments of vulnerability, beetle populations, values at risk, and knowledge of industrial capacity and license agreements at the local level – all beyond the scope of this report. Instead, this section establishes the factual context for addressing response. This section also identifies some specific decisions under consideration and the sequence of actions that must be taken to facilitate plans on immediate action.

3.1 The Need for a Response

It is possible that mountain pine beetle populations outside the historic range could subside without any intervention and remain endemic, posing no risk at all to boreal and eastern pine stands. However, this is unlikely. The past decade of favourable climatic conditions and availability of suitability hosts demonstrates the reality of the risk.

Based on the above, most likely future scenarios include:

1) Persistent low-level mountain pine beetle populations outside the historical range which are widespread and difficult to contain;

2) Potential for damaging outbreaks over the long-term when favourable weather conditions occur;

3) Development of an ecological pathway across the prairie region that would allow continued spread of mountain pine beetle further east into areas with more susceptible pine forests.

A comprehensive response will require a variety of management actions based on objectives specific to local outbreak conditions, stand vulnerability, values at risk, and feasibility. The consensus among participants in this assessment was that a "do nothing" strategy would likely exceed the risk tolerance of stakeholders in the regions under threat. A response based on current information and knowledge would include both short-term direct control and longer-term preventative management. Furthermore, information gaps that have been identified in this report need to be filled. Although these do not represent an exhaustive gap analysis of mountain pine beetle research, some of the information needs that have been identified here will allow improved assessments of mountain pine beetle risks in the future, and will aid the development of successful and cost-effective control strategies. The most critical information need is for effective monitoring and detection in areas most susceptible to the current infestation.

3.2 Control Effectiveness

Despite significant efforts at direct control of mountain pine beetle populations, there are few examples where populations have been successfully suppressed especially when populations reach epidemic status over large areas (Carroll et al. 2006). However, there is evidence that direct control can significantly slow infestation and damage rates from year to year. An early example is reported by Hopping and Mathers (1945) and Hopping (1946) for an incipient epidemic near Banff, Alberta, in the early 1940s. Every tree in the vicinity of the incipient infestation was assessed over two years, and any tree with evidence of mountain pine beetle attack was felled and burned. During the third year, no beetles could be found. More recently, an examination of the efficacy of control efforts applied in north-central British Columbia during the current epidemic concluded that in areas where single tree removal, patch and small block harvesting was applied, the number of infested trees in the subsequent year was significantly reduced relative to untreated areas (Nelson et al. 2006).

Further evidence for the effectiveness of tree removal near incipient infestations is reported by Alberta Sustainable Resource Development ***(http://www.srd.gov.ab.ca/forests/health/conditionsmaps/mountainpinebeetle.aspx)***. A series of maps shows that between 1997 and 2005, aggressive removal of baited trees between the Willmore Wilderness Area and Waterton National Park was associated with no eastward movement of the mountain pine beetle in this area.

3.3 Response Options

The scope of the risk response decision, in general, is summarized as follows:

A. No response

The decision to take no response explicitly accepts the risks outlined in this risk assessment. It considers the potential consequences of no action to be of sufficiently low probability or impact to justify no further action. New information may invoke re-evaluation of this decision.

B. Further assessment

The assessment may reveal sufficient information to conclude that the risk is unacceptable, but insufficient information is available to formulate an effective response. Critical gaps in information need to be filled to further refine and optimize response decisions. This will be at least partially true in all risk analyses because of the inevitability of imperfect knowledge and the feedback between response and assessment that is characteristic of adaptive management.

C. Short-term, affirmative response

A short-term, affirmative response addresses the immediate threat using direct control tactics. The objective of direct control is to reduce density of local beetle populations and consequently reduce the local rate of increase and the impact and/or reduce the spread of mountain pine beetle into adjacent, un-infested stands (Carroll et al. 2006).

D. Long-term, preventative response

A long-term preventative response applies stand-level management to reduce mountain pine beetle populations to below the outbreak level and to prevent successful immigration from distant, infested stands.

3.4 Analysis

Consensus of workshop participants was to recommend against the no-response option (A). The factual information reviewed and presented here leads to the conclusion that the risk of mountain pine beetle expanding its range north in British Columbia and into the boreal forest in Alberta is real and imminent. Although the absolute magnitudes of the economic and ecological impacts are uncertain, a negative net impact is likely from a new and uncertain disturbance agent in these areas. Moreover, further expansion of the mountain pine beetle's range into the boreal region will establish an ecological pathway that will endanger all Canadian pine resources.

The affirmative response recommended involves continued assessment ***(B)***, short-term response ***(C)*** and long-term response ***(D)***. A general decision-support framework can be found in Shore et al. (2006).

Under ***B,*** there is a need for additional information on the actual status and likely spread rates and pathways of existing populations. Key information that is required for improving immediate decisions on management response include:

1) Extent and specific locations of known mountain pine beetle intrusions beyond the historical range, especially location of the leading front;

2) Rates of attack, survival and brood production in these populations;

3) Rate of decline of mountain pine beetle density in source populations;

4) Sufficient forest inventory maps that can be combined with climatic suitability maps for the boreal plain;

5) Detailed maps of the boreal area at risk and identification of areas most susceptible and their spatial distribution in relation to pathways of invasion and target areas of intervention.

Under ***C***, there is a need to identify clearly the priority of objectives of immediate, direct control. These range from the recovery of values from infested stands with tactics such as salvage logging to slowing the spread by suppressing mountain pine beetle populations and maintaining them at low levels in areas of high susceptibility. While consideration of these various objectives is common to all mountain pine beetle infestations, in the present context we are focussed on reducing the spread of the mountain pine beetle into novel forest environments. Whether that can be best achieved by directing control at source populations in areas of major outbreaks, along the front of the expanding population, or some combination of the two, must be examined. A credible feasibility study will use the information contained in this assessment, enhance it with the best current information on the current status of populations, and expert opinion on the efficacy of associated control tactics. Criteria by which the effectiveness of response actions can be judged are critically important.

Under ***D***, the risk of failure of direct control should be considered, at least in the spirit of preparedness. If immediate control efforts fail and, in particular, if short-term weather favours survival of broods and increased likelihood of long-range dispersal, preventative actions aimed at reducing susceptibility and retarding spread in the boreal plain can be implemented. Preventive management for mountain pine beetle is discussed by Whitehead et al. (2006).

4. SUMMARY AND CONCLUSIONS

This risk assessment identified the following key points regarding vulnerability of boreal and eastern pine stands to mountain pine beetle and the potential impacts of future mountain pine beetle activity:

- There has been a recent change in the geographic range of mountain pine beetle in Canada. Mountain pine beetle has invaded a susceptible portion of the Boreal Plains Ecoregion.
- The mountain pine beetle has a wide range of host pine species (Pinus), including jack pine, which it can attack and produce broods.
- The demographics of host pines in the boreal zone immediately at risk is suboptimal for mountain pine beetle in that pine stands are less contiguous, younger and have lower relative volumes than do pine stands in British Columbia. Suitability of these factors, however, increases east of Saskatchewan.
- Current climatic suitability for mountain pine beetle is greatest in central British Columbia and the in the foothills of northeastern British Columbia and western Alberta. Suitability is moderate in central Alberta to Saskatchewan and decreases steadily eastward.
- The dynamic behaviour of beetles on an invasion front, including the rate of spread, will not differ from observed behaviour in similar situations within the historic range.
- Expected volume losses in the boreal forests of Alberta, Saskatchewan and Manitoba will be less than those experienced in British Columbia.
- Boreal forests contain a high proportion of low-volume stands that are already close to the margins of operability for commercial timber harvesting. Mountain pine beetle-related impacts therefore pose a high risk to the operability of these stands.
- Non-timber impacts will have a greater relative significance in the prairie region than in British Columbia. Forest management interventions may come into conflict with non-timber values in some locations.
- Some additional fire risk may be present in post-mountain pine beetle stands.
- Regulatory impacts or changes to fibre flows may result from mountain pine beetle activity.
- Communities are vulnerable to socio-economic impacts resulting from mountain pine beetle as local timber supply may not have the capacity to accommodate mountain pine beetle-related losses. However, the current state of other industries (such as oil and gas) relative to the forest sector may improve the adaptive capacity of some communities.

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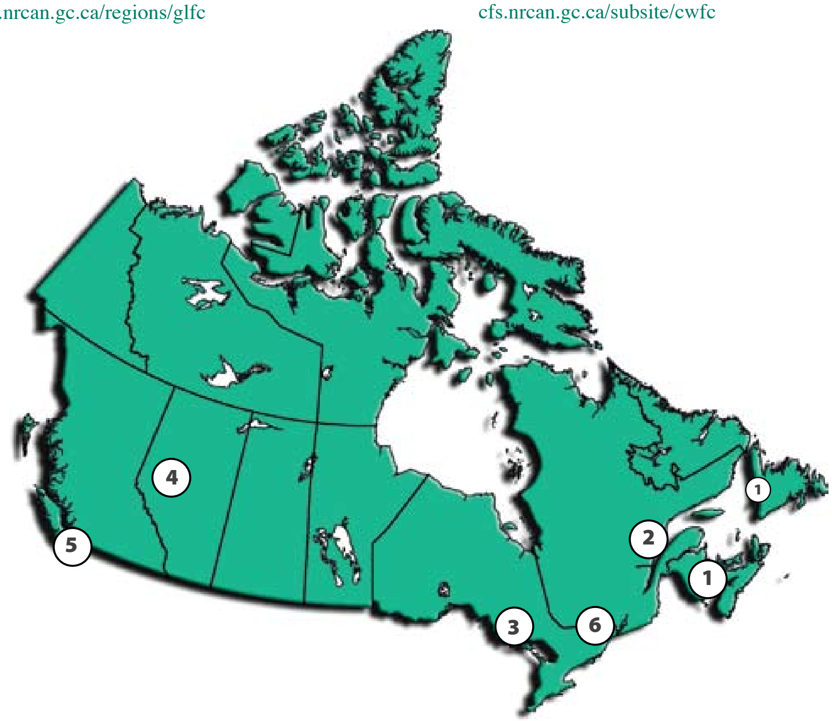

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